Development and Application of an Integrated BIM-GIS System for the Energy Management of Buildings

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Abstract: - Urban planning and land cover management represent crucial challenges in the design and sustainable development of cities from the perspective of energy management. This article presents a methodology for integrating Building Information Modeling (BIM) and Geographic Information Systems (GIS) as an advanced tool for building energy management, allowing to combine detailed information about the physical aspects of the building with geospatial and environmental data. While BIM enables the integrated design, construction, and management of buildings and infrastructure, GIS provides spatial analysis based on geographical data. However, integrating these two approaches is complex, particularly regarding data formats, scale, and accuracy. This study, therefore, presents the application of a new integration environment, Autodesk InfraWorks, which combines Autodesk Revit and ArcGIS for a complete visualization of models in a GIS context. Illustrating the implementation of this approach in an energy efficiency project in the Municipality of Reggio Calabria (Italy), this article demonstrates how the convergence of BIM and GIS can improve urban planning and land cover management, promoting sustainable development practices in the city. This integration has the potential to significantly benefit urban power systems by offering a holistic view of building energy management within a broader urban context. It enables urban planners to make informed decisions that consider energy efficiency, environmental sustainability, and overall urban development, leading to a more efficient and resilient power system.

Key-Words: - Land cover, urban planning, BIM, GIS, integration, Infraworks, laser scanner, point cloud, energy management

1 Introduction

Urban planning and land cover management form the basis of the design and sustainable development of contemporary urban areas. The constant increase in population and the expansion of urban areas have made it imperative to develop advanced approaches to efficiently manage the urban fabric and natural resources. In this context, urban planning is configured as the core to create resilient, efficient, and future-oriented urban communities, [1]. On the other hand, land cover management plays a crucial role in the physical distribution of land surfaces and natural resources within urban areas, significantly contributing to defining the quality of the urban environment and optimizing the use of resources available. The growing awareness of the importance of sustainable urban planning has triggered the search for innovative solutions to address the complex challenges related to urban growth,

reducing environmental impact, and improving the quality of life in cities. In this context, the article aims to explore the synergistic integration of two advanced technologies: Building Information Modeling (BIM) and Geographic Information Systems (GIS), [2], [3]. These two approaches, if carefully integrated, can provide a comprehensive and interdisciplinary framework for urban planning and land cover management. The application of BIM in the context of urban planning paves the way for integrated design, realistic visualization of projects, performing detailed analyses (e.g. optimizing energy efficiency), and long-term management of urban infrastructure. On the other hand, GIS allows us to perform analyzes based on demographic, environmental, and infrastructural data, revealing trends and opportunities in urban planning, [4].

Despite the promising potential for integration,

successfully addressing the convergence of BIM and GIS in urban planning involves complex challenges due to the substantial inherent differences between these technologies and the need to synchronize these differences synergistically, [5], [6]. Among the most significant challenges, the management of the distinct data formats used by BIM and GIS stands out. Furthermore, the intrinsic complexity of BIM models can complicate the harmonization with the more holistic vision typical of GIS, [7]. BIM models incorporate a multitude of intricate building and infrastructure details that don't always integrate effortlessly with the broader perspective of GIS. The challenging technical task is to eliminate this format difference and ensure smooth data exchange between the two platforms. Another crucial aspect concerns the delicate balance between scale and precision. BIM focuses on building-level detail, while GIS operates on a larger geographic scale. Effectively combining these different perspectives without compromising the integrity of each presents a significant challenge. Accurate data handling is a prerequisite for successful integration.

In the literature it is possible to find several articles dealing with the integration of these two systems whose interoperability and connection could bring numerous benefits, [8], [9].

Other authors have experimented with similar approaches and have outlined the main advantages and disadvantages of this method. Certainly, the InfraWorks software provides spatial analysis capabilities, such as measuring the distance between buildings and important points of interest, as well as evaluating accessibility from the road network. This integration enables project managers to quickly visualize buildings and access relevant project information. Moreover, this method offers the advantage of including all information about buildings in a single file, minimizing documentation loss. Some of the drawbacks of this approach, as highlighted by, [10], [11], include an incomplete reading of BIM data and, consequently, a lack of complete interoperability, although the platform is undoubtedly a simpler way to assist urban planners in building urban energy systems.

In this context, the present study aims to examine the implementation of an integration environment, known as Autodesk InfraWorks, which combines the capabilities of Autodesk Revit and ArcGIS to allow a complete visualization of models in a GIS context. Furthermore, through the illustration of a practical application of this integration in an energy efficiency project located in Reggio Calabria, Italy, it is demonstrated how the convergence between BIM and GIS can be substantially useful in the

approach to urban planning and land cover management while promoting sustainable development practices within cities. BIM-GIS integration offers a comprehensive approach to improving the energy management of buildings, enabling more informed and sustainable decisions through the combination of detailed building data with geospatial information. This is done through the georeferencing of BIM data to visualize the building on geospatial maps, the integration of climate data to optimize energy systems, the analysis of land and topography to influence energy design, the management of natural resources for related decisions to energy efficiency, real-time monitoring of energy use via sensors, environmental impact analysis for sustainability, and expanding integration for sustainable urban planning and management of energy networks. While aware that there are various methodologies intended (on which work is still being done today, with particular reference to the interoperability of the data format), [12], [13], [14], [15], [16], [17], for the effective integration of the two systems, this method can be a valid alternative from the point of view of urban planning is used to evaluate a priori the interventions to be carried out on buildings, (including costs and environmental impacts), making the most of the potential of the two methodologies. With rapid urbanization, the urgency for energy efficiency in cities has intensified. Its implementation is crucial in reducing energy consumption, promoting environmental sustainability, and ensuring energy resilience. In response, urban energy systems now prioritize efficient, sustainable, and reliable energy supplies. At the heart of these systems lies energy efficiency, a crucial factor in minimizing energy usage and promoting environmental sustainability within cities. To this end, this article presents a novel method that uses Infraworks to implement energy efficiency solutions in a specific urban area. Using BIM technology together with Infraworks provides a profound comprehension of urban infrastructure and energy resources to be managed in a more complex energy power system.

2 Materials and Methods

To concretely demonstrate the effectiveness of the integration of BIM and GIS systems, the research conducted adopted a method that focused on the use of Autodesk InfraWorks software, designed to combine geospatial data, typical of the GIS environment, and models three-dimensional generated by BIM modeling. This methodology was

applied to an existing building located in the Province of Reggio Calabria. This approach once extended to the entire urban area, will allow obtaining a complete and integrated view of the crucial information for urban planning and land cover management.

The study methodology is divided into three key phases:

Survey Phase: In the first phase of our study, an in-depth survey activity was carried out using a high-level precision instrument: the FARO CAM 2 laser scanner (Figure 1).

Fig. 1: Instrument for the survey operation of the building in question: FARO CAM 2.

In the context of survey planning, the survey engineer must carefully plan the layout of the laser station to ensure complete coverage of the area of interest. It is essential to locate strategic survey points so that the laser station can scan efficiently and accurately. These reference points have to be connected through point cloud registration, ensuring spatial coherence between different portions of the point cloud acquired from different locations, [18].

The processing of the acquired data is a critical phase of the survey process, [19], [20], [21], [22], [23], [24]. For this operation, the "Faro Scene" software was used, known for its ability to manage and analyze large amounts of 3D scan data. The main stages of processing include:

1. Registration of Individual Scans (Clouds): Scans taken from different locations are registered and aligned with each other to create a coherent view of the survey area.
2. Single Project Cloud Creation: The acquisitions of the Laser Scanner are combined to create a single 3D point that could represent the case study area.
3. Cleanup of the Project Cloud: In this phase, the point cloud is cleaned to eliminate the parts near the building in the exam that are not necessary for the study. This was made to improve the

level of accuracy and the quality of the data acquired with the Laser Scanner.

4. Point Decimation (Resolution): After the elimination of the unwanted information, it was necessary to reduce the density of points to speed up the computational phase and simplify the analysis of the point cloud.
5. Cloud export (E57 format): Finally, the point could be exported in an internationally recognized file format called .E57 format which is a common format used to exchange and store 3D point clouds

The main goal of this survey conducted with FARO CAM 2 was to acquire highly accurate data that would form the basis for subsequent modeling and analysis.

3D modeling phase in BIM environment (Autodesk Revit): After the survey phase that allowed to acquisition of essential information about the study area, the attention was moved to create a, starting from this point could, to create a detailed 3D model of the building, [25], [26]. The model was created using a common modeling software called Autodesk Revit, known in the field for creating highly accurate 3D models.

However, a conversion process through the Autodesk Recap was required before the data acquired from the laser scanner could be used. The BIM modeling process was started by converting the three-dimensional point cloud generated by the laser scanner from an .E57 format into a Revit-compatible format, i.e. .rcp (Autodesk Recap Point Cloud). This step is crucial as it allows to import and use of the survey data within Revit, thus facilitating the creation of a complete and detailed BIM model of the actual state of the building (Figure 2).
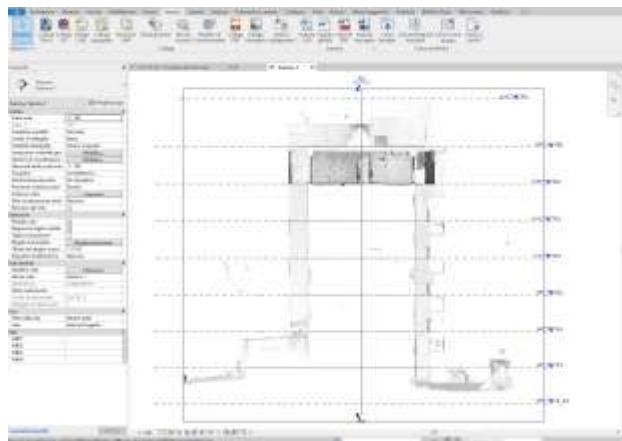

Fig. 2: Software used for 3D modeling: Autodesk Revit.

As regards the interior of the building, for the 3D construction, it was decided to start from the DWG plan, [27].

Modeling Phase of the Geospatial Environment in Autodesk Infraworks with Model Import from Revit: After completing the BIM modeling phase of the building using Autodesk Revit and Autodesk Recap, the focus shifted to modeling the surrounding geospatial environment, [28], [29]. Initially, data layers from ArcGIS were imported into Autodesk InfraWorks. By importing these layers, it was created a detailed visual representation of the geospatial environment within InfraWorks. Once the geospatial data was imported, it was possible to visualize elements such as terrain, roads, water networks, and other details relevant to urban planning and land cover management directly within Autodesk InfraWorks. Subsequently, the 3D model created in the BIM modeling phase with Autodesk Revit was imported into Autodesk InfraWorks.

This 3D model represented the building under study, with all the architectural and structural details. Importing the BIM model into InfraWorks allowed the building to be positioned precisely within the displayed geospatial environment, ensuring accurate alignment between the model and its surroundings (Figure 2). GIS coordinates are used to determine shared coordinates between various models. The same GIS coordinates are used to define the real position (latitude and longitude) of the Revit model. This location is used to perform an accurate energy analysis of the model.

Within Autodesk InfraWorks software, many specialized features can be leveraged to streamline the design and planning process, [30], [31], [32]. One of the key features is Advanced Terrain Modeling, which allows to creation and editing of detailed digital terrain models. In addition, InfraWorks offers the ability to perform an Environmental Impact Analysis to evaluate the influence of infrastructure on the surrounding environment, including hydrology and soil stability. Traffic and Mobility Planning is simplified through traffic flow simulation and optimization tools. For the design of bridges and pipelines, the software offers advanced modeling capabilities. The integration of GIS data is facilitated, allowing you to work with thematic maps and environmental data. InfraWorks allows to creation of Realistic Simulations of infrastructures designed for a clear visualization of the final results. With the Analysis of Project variables, it is possible to explore different options to evaluate costs, efficiency, and environmental impact. The software used for

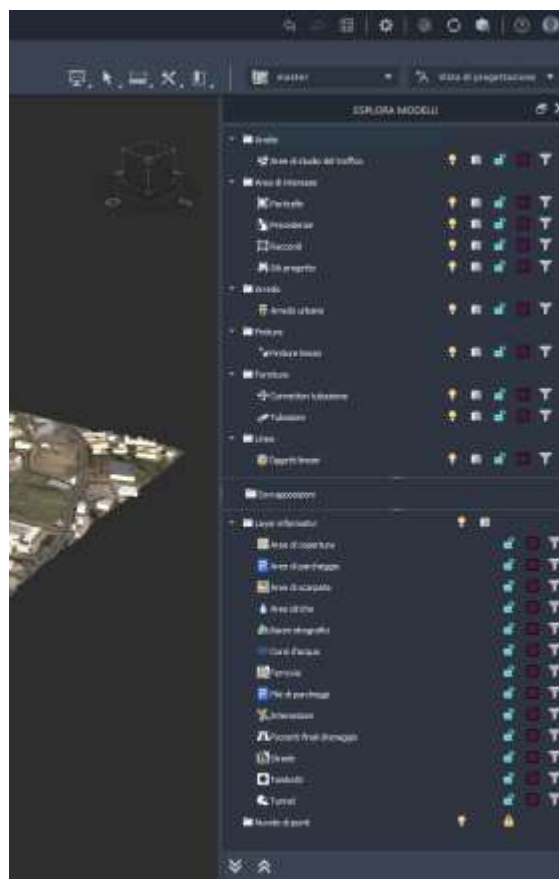modeling the geospatial environment: Autodesk Infraworks is presented in Figure 3.

Fig. 3: Software used for modeling the geospatial environment: Autodesk Infraworks.

3 Results

This methodology has been applied to a building located in the province of Reggio Calabria.

As regards the first survey phase, Figure 4 shows the point cloud displayed in Autodesk Recap derived from the Faro Scene software once the survey of the exterior of the building has been carried out using the Faro CAM 2 laser scanner. In this case, the tool used for surveying was positioned at various points in the area in front of the building, and multiple scans were taken to create the most accurate possible reconstruction of the building. Through the software, it was possible to merge all the scans and create a single-point cloud. In this instance, the instrument also captured the areas adjacent to the building in question, which were subsequently cleaned up. The figure displays the entire surveyed area before the point cloud cleanup. The building under examination is located at the center of this point cloud.

Fig. 4: Point cloud of the building in question displayed on Autodesk Recap.

Since the point cloud of the internal environments was not available, it was necessary to build the 3D model using the DWG plan, shown in Figure 5.

Fig. 5: DWG file of the interior of the building useful for the construction of the 3D model.

As regards the second phase of 3D modeling in the BIM environment (Autodesk Revit), Figure 6 and Figure 7 show the modeling of the interior and exterior of the building.
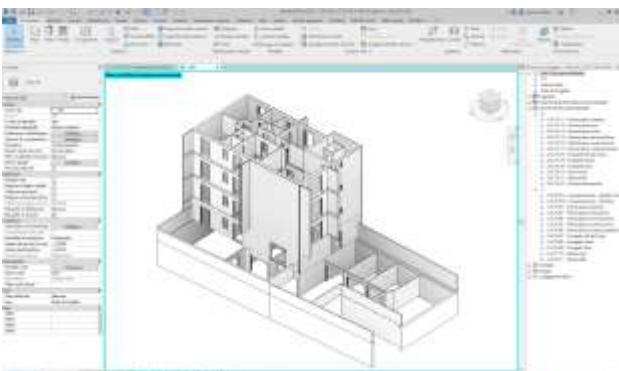

Fig. 6: Autodesk Revit: modeling of the interior of the building.

Fig. 7: Autodesk Revit: Building exterior modeling.

In the *Modeling Phase of the Geospatial Environment in Autodesk Infraworks*, the methods of importing the building from Revit into Infraworks are presented. To use the data layers available from ArcGIS, Autodesk Connector for ArcGIS was employed, which allowed the data layers to be directly added to Autodesk Infraworks models. To do this, we logged in using ESRI ArcGIS credentials. Once logged in, Autodesk Connector for ArcGIS was used to search for available datasets. To complete this operation, it was first necessary to select the area of interest, as shown in Figure 8, by entering the longitudinal and latitude coordinates, and then choosing the desired layers. In this phase, it was possible to select the coordinate system (which must necessarily coincide with the coordinates entered in Revit) and also the dimension of the selected area. In this specific case, the chosen area (as also displayed in the figure) measures 1.62 km². In this study, we included models of the surrounding buildings and transport infrastructure in the surrounding area of the building under study, as depicted in Figure 9 a and Figure 9 b.
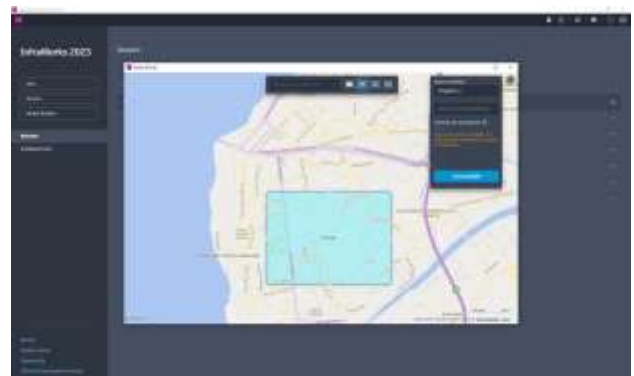

Fig. 8: Autodesk Infraworks: choice of the study area for displaying the layers available in the area.

Fig. 9a: Autodesk Infraworks: example of inserting layers useful for the application.

Fig. 9b: Autodesk Infraworks: visualization of the building correctly georeferenced on the map and of the layers chosen during the modeling phase of the GIS environment in Infraworks.

As can be observed from Figure 9a, the existing transport infrastructure in the area has been incorporated. In this case, it mainly consists of urban roads and, to some extent, expressways. The layer downloaded from ArcGIS Online containing 3D models of the surrounding buildings schematically represents each building, depicting it as a cube with a low level of detail. In the 3D model of the case study building, instead, a high level of detail has been achieved. It is possible to view the constituent elements, such as fixtures, windows, and other structural components of the building, allowing for a comprehensive and complete evaluation and visualization.

Finally, Figure 10 illustrates the potential of the software in interrogating the various models inserted, to carry out a correct evaluation of the interventions to be carried out on the building in question, allowing the estimation of the costs and times of energy efficiency interventions. In this specific case, the analysis conducted using Infraworks made it possible to evaluate the installation of photovoltaic panels on the entire wall of the building.

Fig. 10. Autodesk Infraworks: case study application.

Figure 11 shows the building correctly integrated into the urban context, where it is possible to visualize the specific energy efficiency interventions included in the project phase. Furthermore, InfraWorks allows for querying the objects within the project, providing information such as the building's type of structure or roofing material. This methodology extended to a wider area could be useful in the effective management of urban planning with a view to optimal urban energy management, simplifying informed decision-making in urban planning. Indeed, InfraWorks provides tools capable of conducting detailed terrain analyses, including slope calculations, altimetric profile analysis, and terrain modeling. When these tools are combined with data from Revit, it becomes possible to efficiently assess the energy, environmental, and structural aspects of an urban area. It can perform, in fact, land cover analyses, environmental impact assessments, surface water modeling, and energy efficiency evaluations of buildings.

Fig. 11: Autodesk Infraworks: visualization of the building of the case study.

4 Conclusion

In this research, we examined the implementation of an innovative integration environment, known as

Autodesk InfraWorks, which combines the capabilities of Autodesk Revit and ArcGIS to provide a comprehensive view of models in a GIS context. Through a practical application of this integration in an energy efficiency project located in Reggio Calabria, Italy, we have demonstrated how the convergence of BIM and GIS can transform the approach to urban planning and land cover management while promoting sustainable development within cities. It is important to note that, although there are several evolving methodologies for the effective integration of BIM and GIS systems (with particular attention to the interoperability of data formats), the method examined in this study is configured as a valid alternative in the field of urban planning. It can preventively evaluate the interventions to be carried out, including costs and environmental impacts, exploiting the full potential of the two methodologies.

The integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) in the context of urban power systems is a powerful technical advancement. This collaboration equips urban planners and power system engineers with a wealth of data to optimize a city's energy management.

The integration of the two systems has the following advantages:

Understanding Energy Usage: At the heart of power systems is the need to comprehend how electrical load is distributed throughout an urban area. The fusion of BIM and GIS enables a precise, detailed view of how buildings use energy. Planners can assess how power demand is distributed across the city, pinpoint areas with high energy needs, and plan improvements to the infrastructure.

Boosting Energy Efficiency: In contemporary power systems, energy efficiency is of utmost importance. BIM's detailed building information provides valuable insights into energy consumption patterns. It helps identify which structures are energy-efficient and which ones require retrofitting. By focusing on specific buildings or areas for energy efficiency enhancements, urban power systems can reduce overall energy demands and enhance resilience.

Embracing Renewable Energy: The integration of BIM and GIS aids in selecting ideal sites for renewable energy installations, such as solar panels and wind turbines. This approach combines geographical data with building-specific details, making it easier to locate rooftops and areas with the greatest solar exposure or wind potential. This facilitates the integration of clean energy sources into the power system.

Building Resilience: Power systems must withstand external factors like extreme weather events. BIM and GIS help assess vulnerabilities and plan for contingencies. By mapping critical infrastructure components, understanding their interconnections, and visualizing potential weaknesses, urban planners can devise strategies to enhance power system resilience.

Optimizing Infrastructure: Effective urban power systems rely on well-designed infrastructure. The amalgamation of BIM and GIS streamlines infrastructure planning, from determining the best substation locations to designing efficient distribution networks. This integration also aids in predicting future energy demands based on urban growth patterns.

Real-time Insight: BIM-GIS integration enables real-time monitoring of energy consumption and infrastructure performance. By connecting BIM data with sensor networks and IoT devices, urban power systems can gather real-time data on electricity usage, equipment health, and environmental conditions. This data becomes invaluable for predictive maintenance, load balancing, and efficient energy distribution.

The further development of this approach may involve investigating the possibility of creating a model to identify optimal construction material sites and efficiently manage demolition waste. Additionally, it could be useful to expand the study on a larger scale by incorporating other 3D models into the area of the case study by offering more comprehensive information, to include all the relevant data for urban planning in one location.

This approach has also other practical applications that concern transportation engineering to design and analyze transportation infrastructure for better traffic flow and safety. It also can assist in environmental impact assessments and plan sustainable solutions for environmental challenges. Lastly, this approach can be used for planning utility infrastructure, including electricity, gas, and water distribution as well as renewable energies.

Although this method is useful for efficient urban planning, the authors are currently conducting further studies to address the issues that may arise from the advanced integration of the two systems.

These studies are based on the use of web-based platforms for visualizing three-dimensional geospatial maps, which make use of customizable libraries within which it will be possible to implement software modules specially designed for format conversion, starting from suitably structured databases. Another interesting solution could be the use of specific apps of virtual/augmented/mixed reality (VR/AR/MR), developed by authors, that allow the visualization and management of BIM models in a virtual environment in which users could interact. These solutions could solve the issues related to this methodology.

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The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

Conflict of Interest
The authors have no conflicts of interest to declare.